# Analysis and Quantification of Uncertainty for Climate Change Decision Aids for Energy Consumption in the Southwestern US

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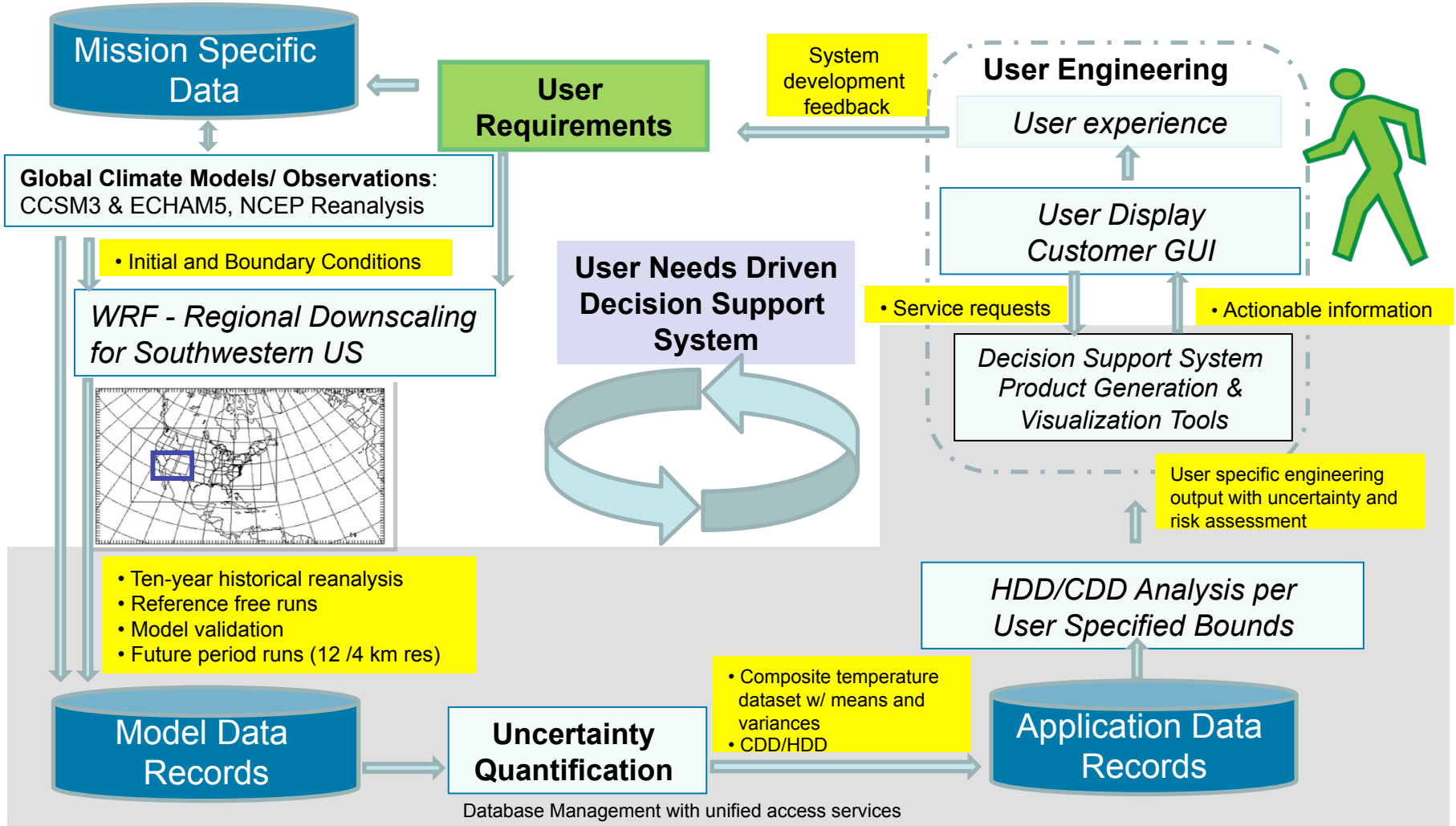
# CKIC - Climate Knowledge Integration Centers

*A Northrop Grumman Climate Initiative Effort*




**CKIC: A systematic framework for producing Actionable Decision Aids, such as Uncertainty Characterized Energy Consumption Scenarios**

# Energy Consumption Modeling Strategy

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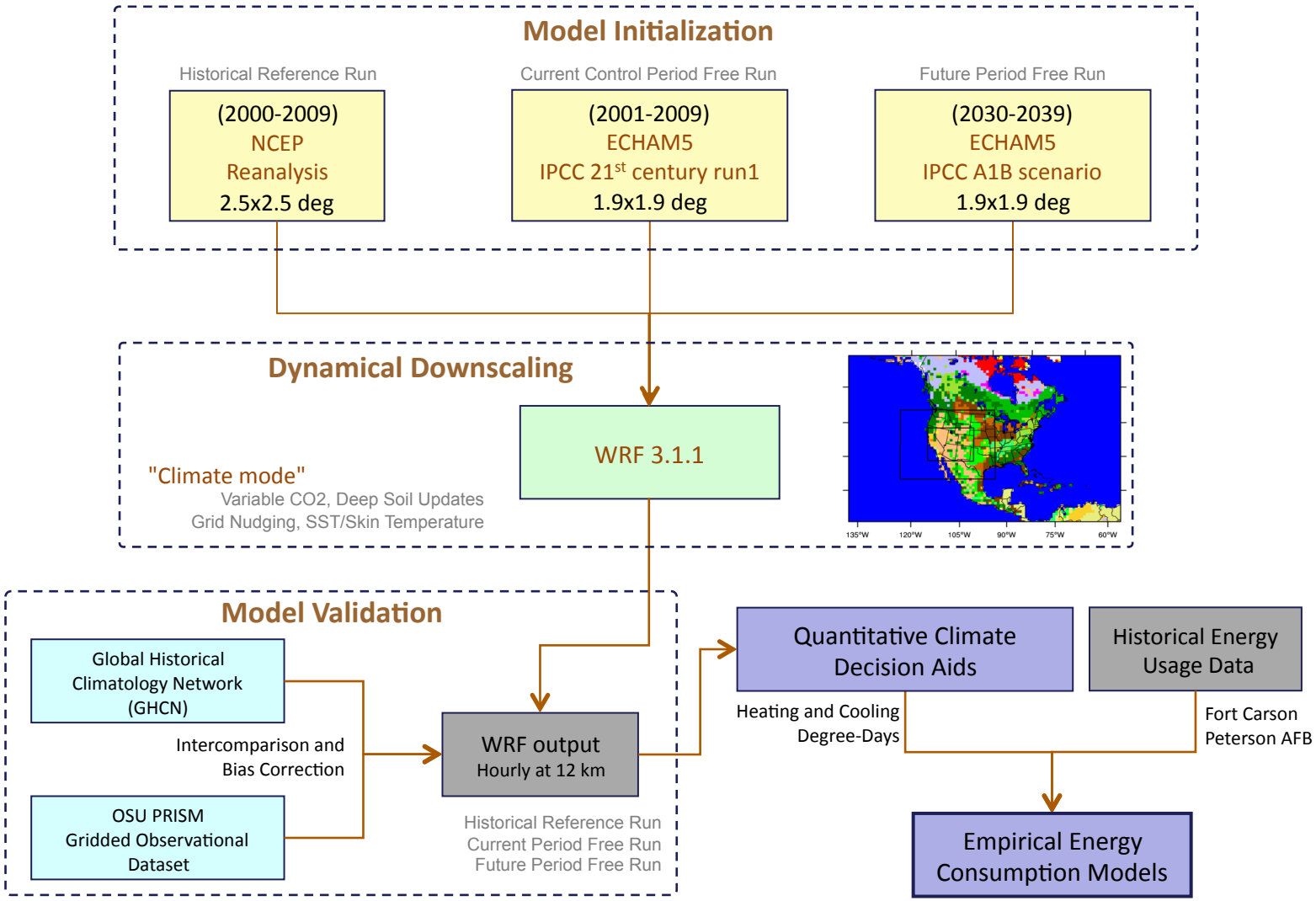
*Providing end-users with actionable climate-model based Decision Aids*

- Problems:
  - Available IPCC models operate at coarse spatial and temporal resolution
  - Climate change signatures are bound up with various modeling system biases
  - Need to characterize Uncertainty objectively to bound utility of results
  - Energy consumption data has operational "flavor" – many non-environmental factors
- Solutions:
  - Downscale IPCC runs using well-regarded regional model – WRF in "Climate Mode"
  - Perform systematic objective bias correction
    - Adjust historical reference runs to match high-quality climatologies
    - Correct model scenario runs for local/time-of-day/seasonal biases in first and second order statistics
  - Bound intrinsic modeling uncertainties using statistical analysis of multiple periods
    - Limited scope of project dictated two, ten year periods of record
    - Produce standard error estimates for all derived decision aids using well-known statistical methodologies
  - Acquire energy consumption data from actual operational facilities
    - Provided by facilities managers from Fort Carson, Colorado; and Peterson Air Force Base, Colorado
      *(These potential end-users were briefed on project results in September, 2010)*
  - Perform regression modeling for energy use
    - Outlier detection
    - Error parameterization and propagation

# Modeling Overview

*Regional Downscaling as a route to Decision Aids*



# PRISM Bias Correction

*Improving Reference Run Accuracy*

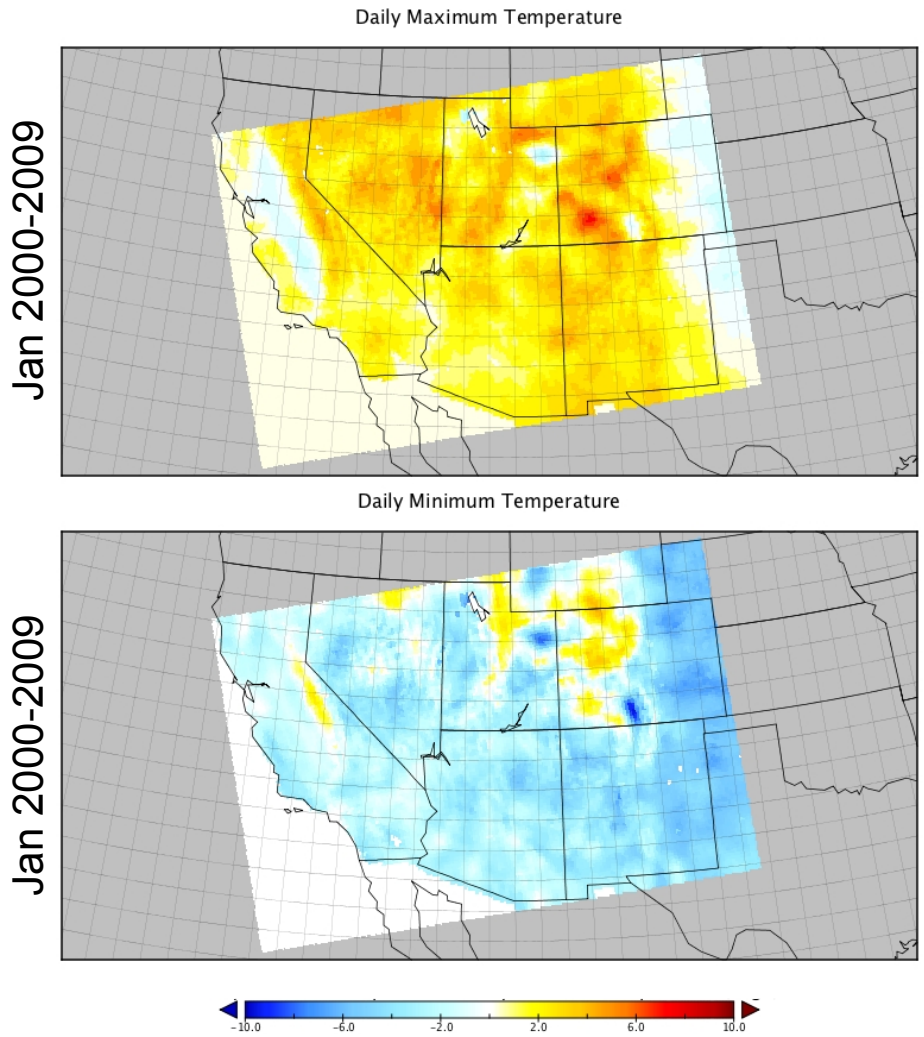
## PRISM Correction Stage

- PRISM Dataset defines Daily High/Low statistics
- NCEP Control run linearly transformed by hour to match equivalent monthly statistics of average highs and lows
- Water bodies and urban land-use cells corrected in local neighborhood

## Notables

- Daily range tends to be increased
- Reservoirs in Eastern New Mexico show out as warm cells
- PRISM data extent does not cover oceans or outside of CONUS US

**NCEP/WRF Historical Reference Run Correction to Temperature Relative to PRISM**




PRISM: "Parameter-elevation Regressions on Independent Slopes Model"
The PRISM Climate Group at Oregon State University

# Bias Correction to Reference Run

*Producing Intercomparable Model Datasets*

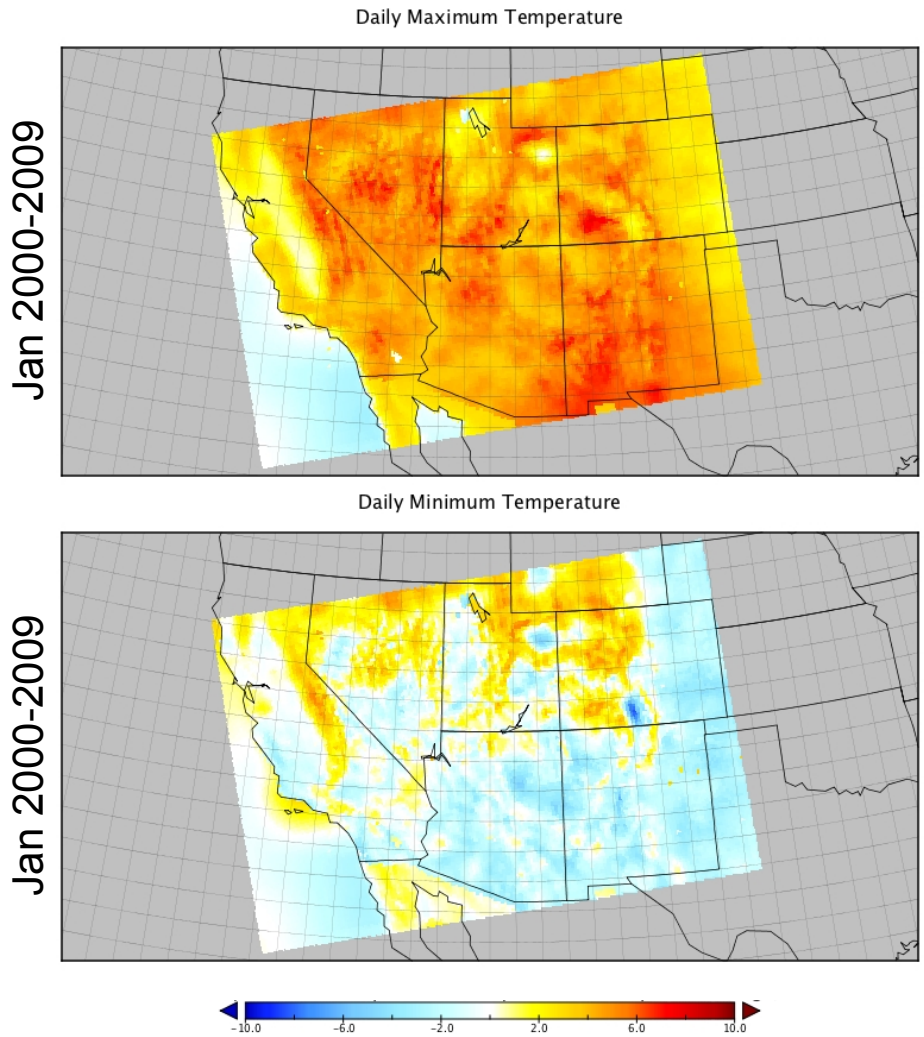
## Bias Correction Stage

- Reference Run Dataset defines Monthly/ Hourly expectations and variances as well as temporal autocorrelations – corrected to match PRISM climatology
- Analysis of NCEP Control Run defines Autoregressive time series transform which removes Monthly/Hourly deviations in first and second order statistics from Reference Run
- Transform applied to both Control and Future period model runs to establish inter-comparability with Reference Run

## Notables

- Daily range tends to be increased in all months
- Reservoirs in Eastern New Mexico show out as warm cells in the minimums
- WRF modeled Urban Heat Islands preserved
- PRISM data extent does not cover oceans or outside of CONUS US

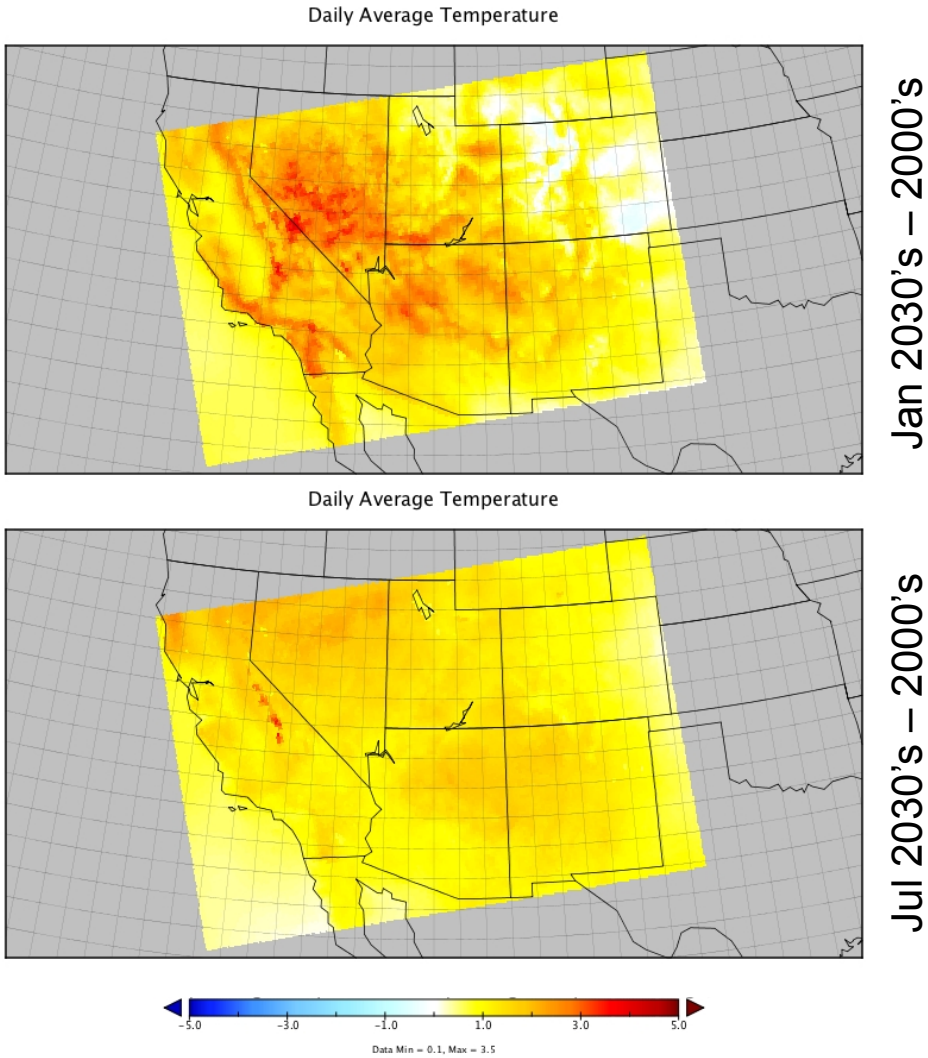
**ECHAM/WRF Control Run Correction to Temperature From NCEP/WRF Reference Run**



# Climate Change Signature

*A1B Regional Climate Change*

**ECHAM5/WRF Future Period – Current Period**




## IPCC A1B Scenario over 30 Years

- 2000-2009 compared to 2030-2039
- Bias corrected to NCEP/WRF-PRISM historical reference sets
- Simultaneous computation of standard error bounds individually by cell

## Notables

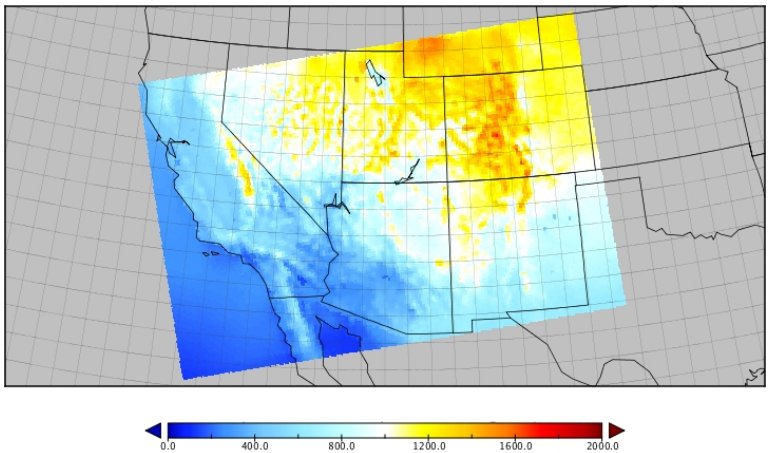
- Overall increase in temperature of 1 to 2 degrees
- Winter temperatures slightly cooler in the high plains of Colorado
- Snowpack differentials between the time periods amplify local temperature signatures

# Degree-Days

*Quantitative Climate Decision Aid for Energy Consumption*

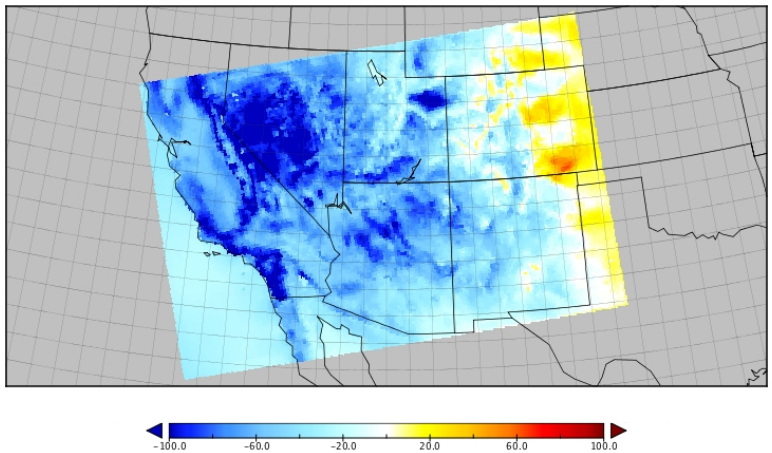
## Computed 65F Baseline HDDs with Standard Error Estimates

Expectation of HDD per month



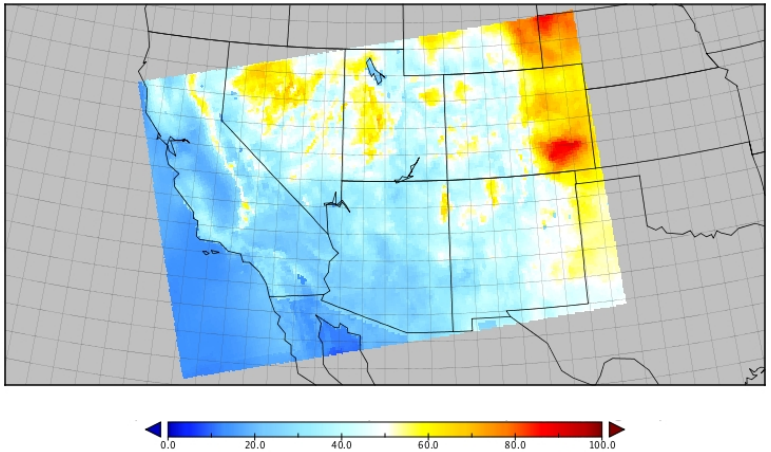

Jan ECHAM/WRF 2000-2009 HDD

Expectation of HDD per month

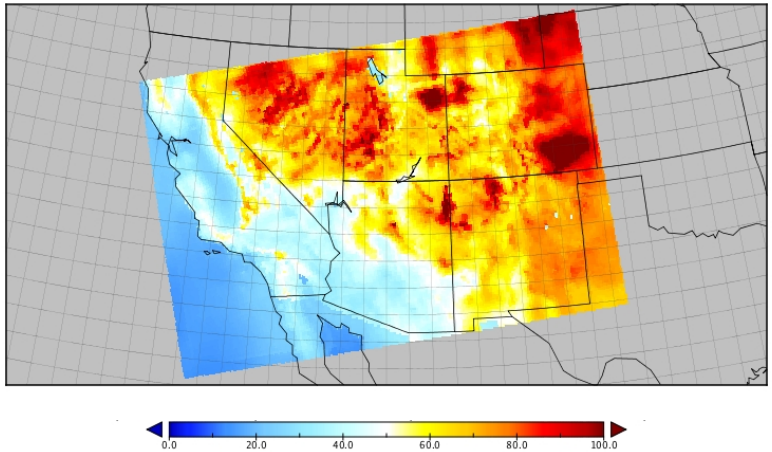



Jan ECHAM/WRF Future – Current HDD

Computed standard error of the expectation of HDD per month




Computed standard error of the expectation of HDD per month



# Energy Model Structure

*Energy Use expressed as a function of Heating and Cooling Degree-Days*

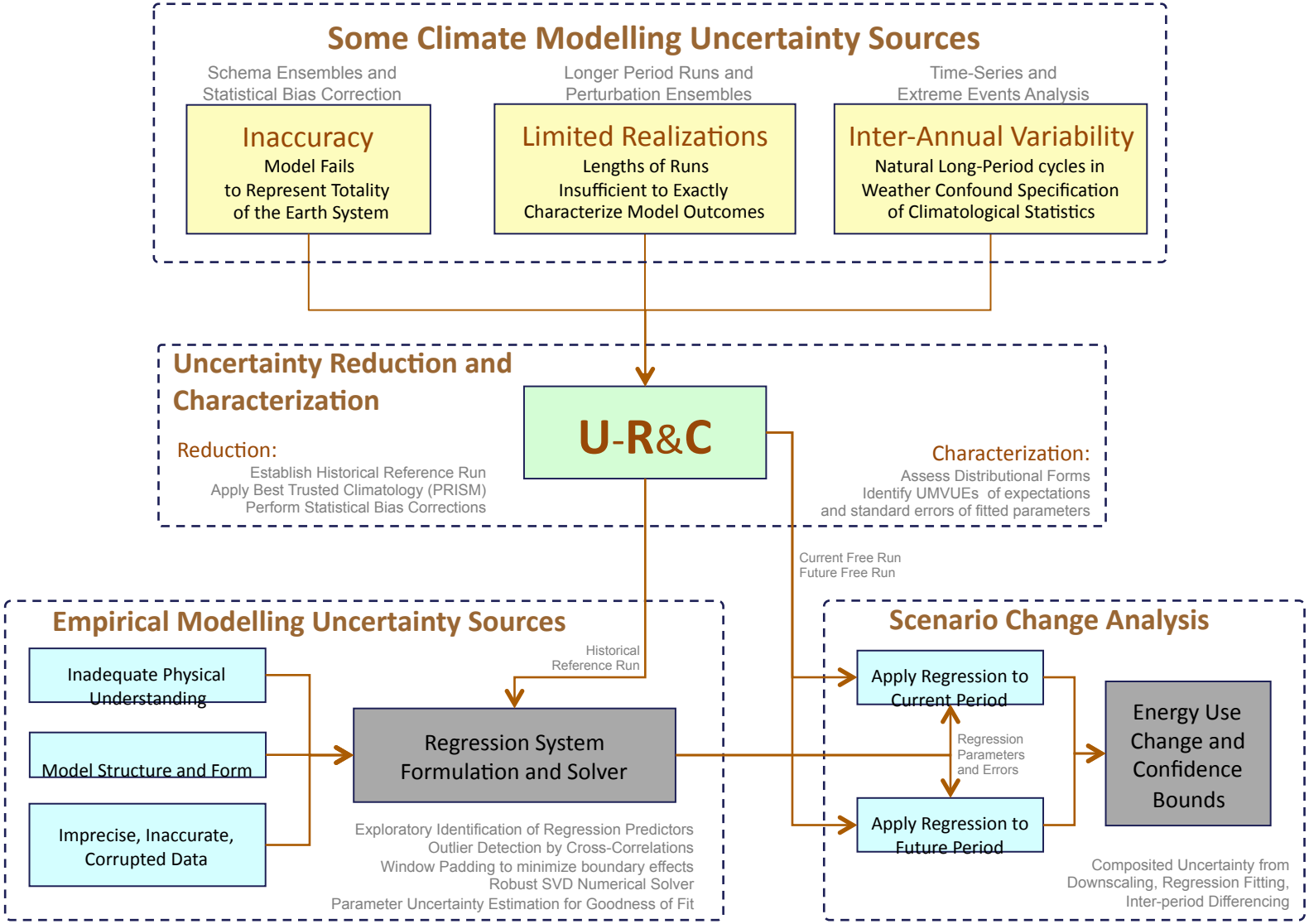
- Real world data from Peterson AFB and Ft Carson showed:
  - Long-period trends driven by outside factors
  - Electrical use trends confounded by these factors
  - Natural Gas usage at both locations seasonally dominated
  - Electrical use having both summer and winter maxima
  - Significant outliers in both datasets

- Energy use per square foot was modeled as a factored linear sum of:
  - Linear Time Trend & Sinusoidals with 10, 5, and 3.3 Year periods
  - Heating Degree Days computed from 55, 65, and 75 deg F bases
  - Cooling Degree Days computed from 55, 65, and 75 deg F bases
  - "Winsor" style window padding at 5% weight level for one year prior and post series.
  - Automated outlier detection

- Classic Linear Regression analysis yielding:
  - Weight factor parameter estimates
  - Parameter error covariance matrix
  - $R^2$ Goodness of fit
  - Residuals for post facto model assessment

# Uncertainty Management

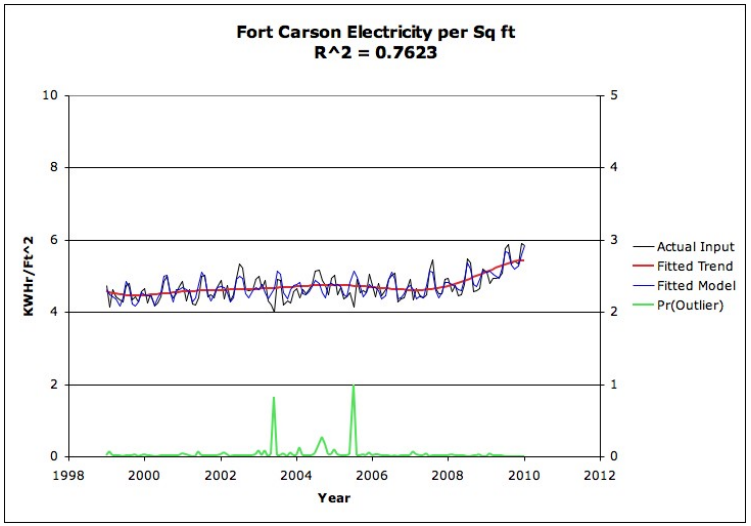
*Uncertainty Quantification expressed as an End-to-End System*

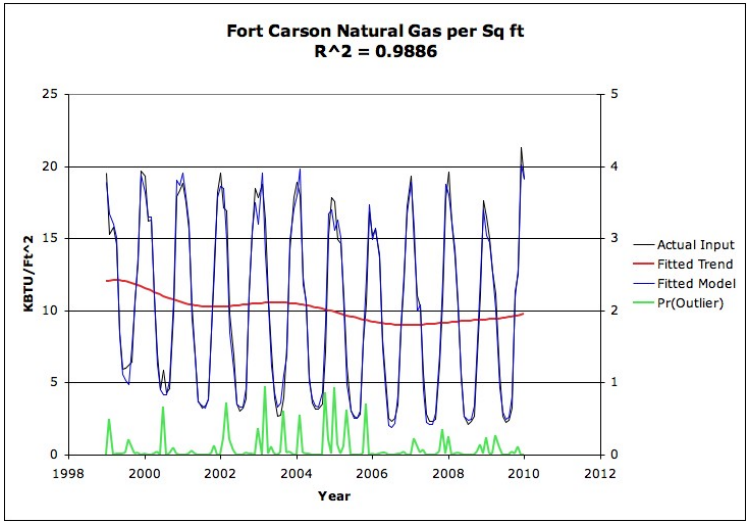


# Fort Carson Data

*Fort Carson hosts 30,000 personnel, with over 10,000 residing on-post*

- Square Footage for Fort Carson was very-roughly estimated to range from 6 Million square feet in 1999 to 9 Million in 2010
- Trends in energy use are shown along with the model's fit and the actual data being fit to
- Fort Carson is well behaved. Unexpectedly, electrical use has a significant double maximum; in both summer and winter – implying electrical power is used for heating or other winter-time seasonal activities as well as cooling
- Many outliers were detected in gas usage, but few were significant with outlier probability very near 1.0



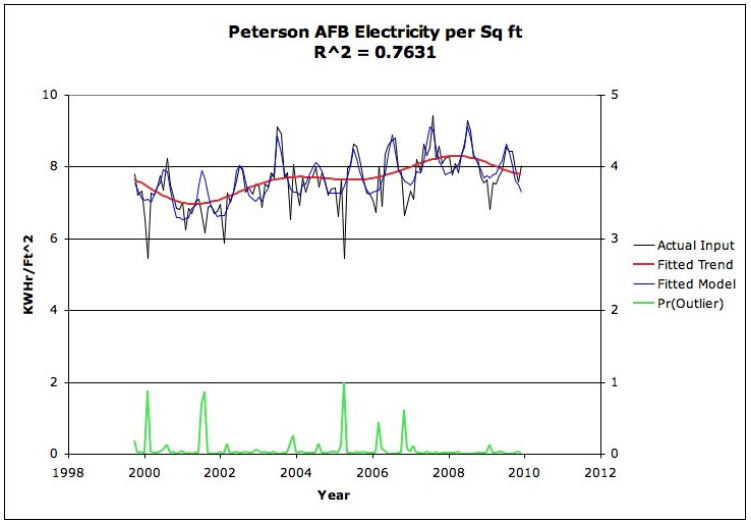

Results here must be treated as notional pending full and accurate specification of building square-footage for both locations. This important variable was fabricated as a placeholder for Fort Carson

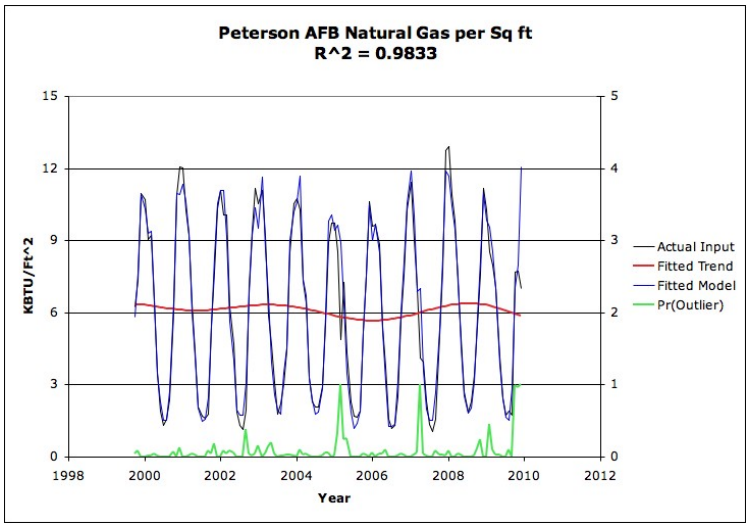
# Peterson AFB Data

*Peterson Air Force Base hosts over 7400 personnel, largely residing off-base*

- Square Footage for Peterson AFB was provided for three fiscal years, and interpolated/extrapolated to the full period
- Trends in energy use are shown along with the model's fit and the actual data being fit to
- Note the significant outliers in both electrical and natural gas use. Outlier deweighting minimizes the effect of these on the models, but at a slight adverse technical effect on the total model fit

Results here must be treated as notional pending full and accurate specification of building square-footage for both locations. This variable was interpolated from three year's actual data to the full period for Peterson AFB

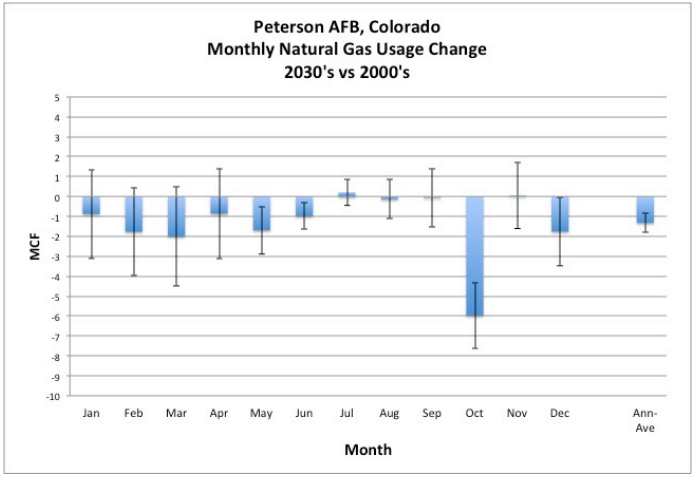


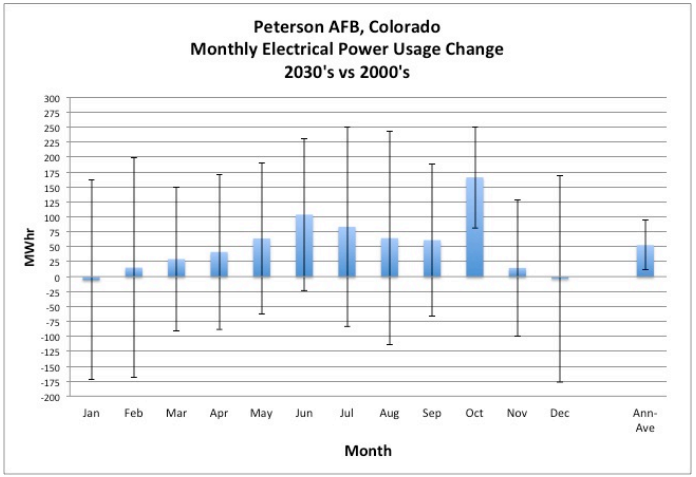



# Energy Consumption Scenarios

*Natural Gas consumption likely to decrease, Electrical consumption more mixed*

## Peterson AFB



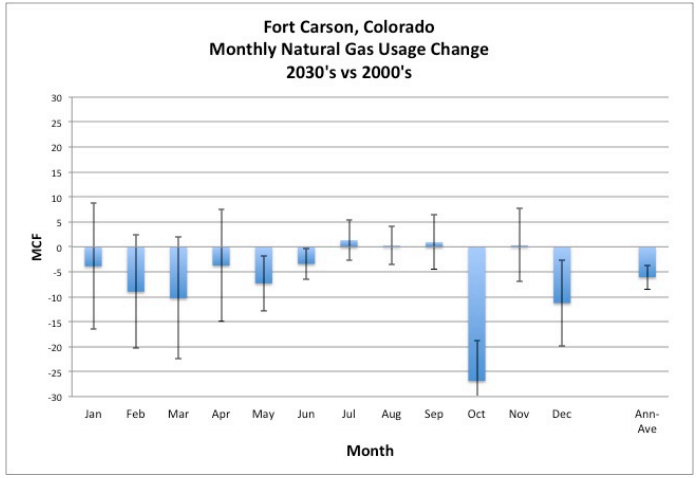



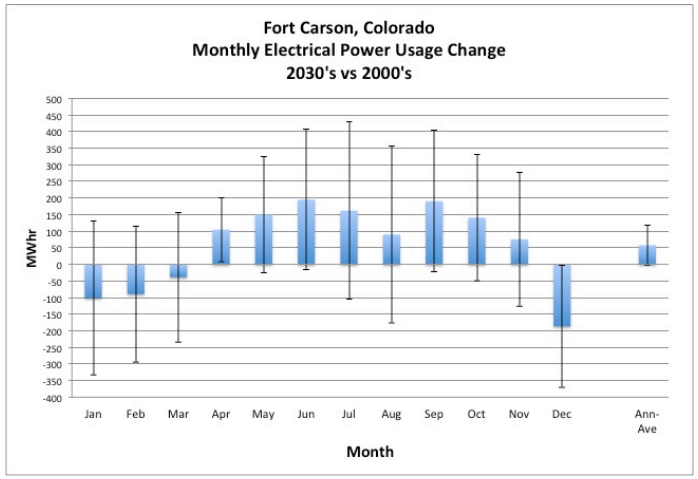

ECHAM/WRF Climate Downscale shows a later onset of winter, with the peak inter-period change being in October

Gas usage in both bases is consistent; error propagation shows a significant annual decrease in use as the climate warms and reduces need for heating fuel

Electrical usage is much more mixed, with a modest increase in power usage for cooling in the warmer summertime maximum

## Fort Carson

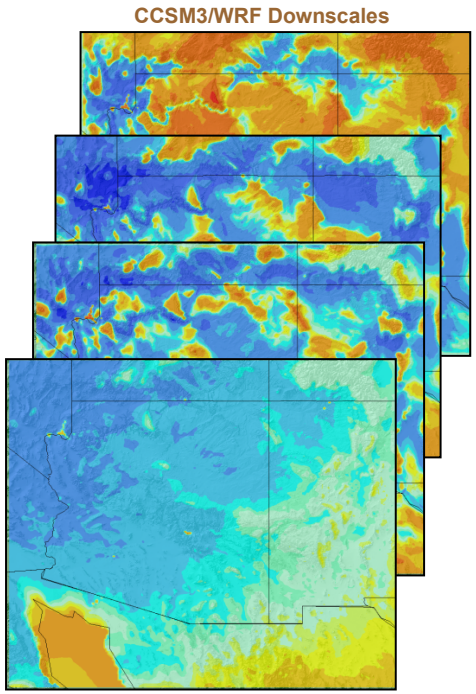


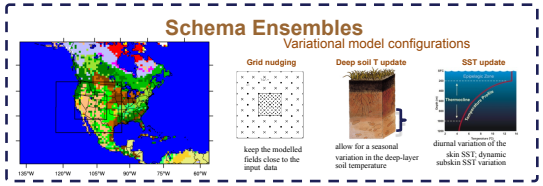



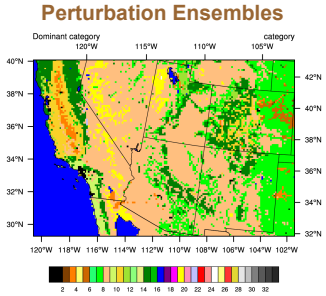
# Future Directions

*CKIC Project continuing to advance Science and Technologies supporting Actionable Decision Aids*

- **New techniques and data in uncertainty reduction and characterization**
  - Local conventional reports driven bias correction
  - Develop new visualizations and user-oriented uncertainty presentation products
- **Multiple Models – ORNL's CCS3/WRF Downscales**
  - Fold into U-R&C process
  - Establish lower bounds on inter-model sources of uncertainty
- **Additional Schema and Perturbation Ensembles**
  - Better characterization of intra-model spreads of outcomes
  - Narrow ranges of standard errors on derived products
  - Provide better capability to represent and characterize extreme events
- **Explore New Application Areas**





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